The Application of the High Speed Diesel Engine as a Light Duty Power Plant in Europe

C.J. Hind

Perkins Engines Company, Peterborough, England

The fact that the diesel engine has been considered and used as a saloon car power unit for some 40 years may come as a surprise to some people. They may admit that this is so but will come back with the reply that it has not made very much progress through the years. The diesel engine succeeded in getting a name very early on, and quite rightly so in some cases, as a dour thumping engine that plods on for ever, and not so flatteringly as a smelly, noisy,and rather smoky power unit. Very few of us would disagree with this description up to say 30 years ago, but great strides have been made since the mid-forties which have elevated the small diesel engine into a much more acceptable automotive power unit. The days when only an enthusiast or an eccentric would drive a diesel powered car are now passing and the wisdom and foresight of those early engineers is now bearing fruit. The design and combustion features of the diesel engine are showing to be more compatible with the strict legislative demands that are being thrust upon us and more people are now looking for a vehicle with good reliability, long life and maximum fuel economy. The words "fuel resources and energy crisis" are becoming commonplace these days and so it is worth remembering that the great redeeming feature of the diesel engine is its excellent fuel economy and low running costs.

But when did it all begin and why?

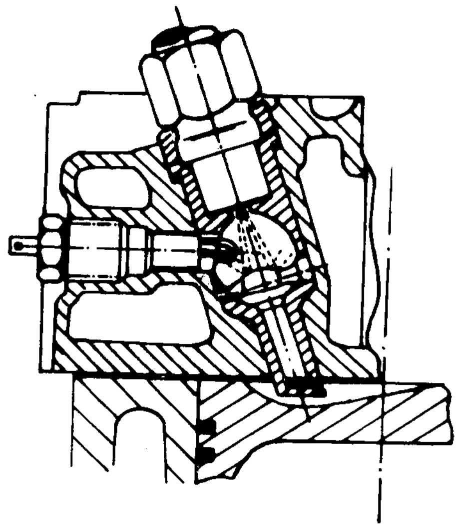
The beginning in Europe.

The early 1930's really saw the first production high speed diesel engines, and these required a whole new philosophy to be applied. The first diesel engines had been very heavy and bulky industrial and marine units with a maximum speed of around 1000 RPM, which made them unsuitable for vehicle applications.

Eventually the fuel economy shown by these engines, along with the attractive low fuel costs, made their progression into the commercial vehicle market a natural move. The rated speeds were raised to around 2000 RPM, although some of them remained below 2000 RPM, and in fact Gardner engines to this day still keep their rated speed in that same speed range.

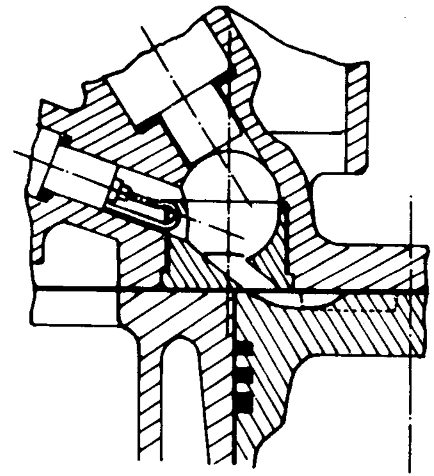
The rapid development of these engines from the mid-1920's to the mid-1930's was very impressive and the commercial vehicle operators attracted by the lower operating costs very soon saw the advantages of the diesel engined vehicle and helped this market to rapidly expand. Various companies, mainly in Great Britain and Germany, were developing these engines, whilst most of the French engines were being built under licence, excluding Peugeot who had extended their very successful petrol engine experience into the diesel engine field in 1928. Those early marine and industrial engines were made even more bulky by the fact that an air compressor was required to help atomise the fuel and provide the necessary air movement for good mixing. With the advent of the Bosch fuel injection equipment in Germany and later when C.A. Vandervell took up the manufacture of Bosch equipment in England, real strides were taken in the development process.

The high speed diesel engine, with rated speeds of 3000 RPM plus came to be used in the light truck market by two different roads. The company who manufactured both trucks and diesel engines saw the high speed engine as a natural extension of his engines in his trucks. The other approach was being made by the



MERCEDES - BENZ

FIG.1.



RICARDO COMET

FIG.2.

diesel engine manufacturer who offered to replace an existing gasolene engine in another company's truck. In the former case a vast amount of experience had been gained in the designing of the diesel engines for the bigger commercial vehicles and from this a large amount of knowledge was drawn which assisted in the development of the smaller units. In many cases the smaller engine was a scaled down version of its bigger brother, and the basic design and combustion principles were very similar.

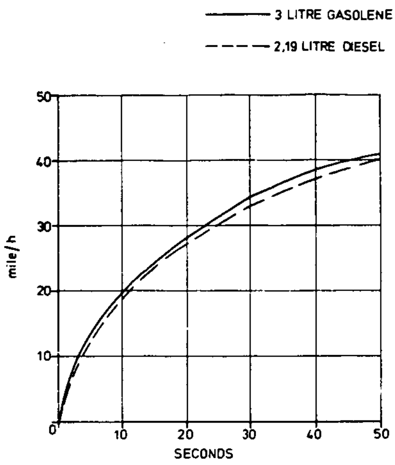
In the latter cases where an existing gasolene engine was being replaced by a diesel engine, a whole new design philosophy had to be applied, because interchangeability was a key factor and the diesel engine had to fit into the space vacated by the gasolene engine. As the transmission of the trucks was again designed for the displaced gasolene engine, this meant that the equivalent diesel engine had to have a similar speed and torque range. All this was a considerable break away from the traditional diesel requirement, and a large amount of design and development work was required.

It was realised early on in the development of the high speed diesel engine that cylinder pressures and engine breathing were going to be prime reliability and performance parameters.

The adoption of an indirect chamber engine allowed the intake port to be concerned only with inducing as high a mass of air as possible, and the swirl properties required for efficient combustion were provided by the air movement into and out of the chamber. Many designs of chambers were evolved during this time, each with its own theory and optimistic efficiency put forward by its inventor. One of the earliest and most successful designs was the Benz, later Mercedes Benz of course, pre-chamber or pepper pot design. This type of chamber has certainly stood the test of time as it is still widely used today and in many sizes of engines. This chamber was first used in the bigger design of engine, as was the well-known Ricardo Comet combustion chamber, which again underwent a smooth transition into the high speed engine, where it is still very widely used. See Fig. 1 and 2.

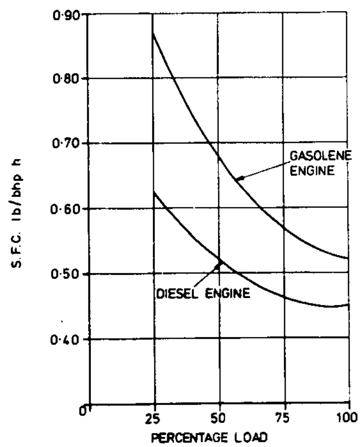
My own Company, Perkins Engines Company, was formed in 1932 specifically to manufacture high speed diesel engines for the lighter class of vehicle. As previously mentioned, interchangeability with the gasolene engine wherever possible was the primary aim. Fig. 3 shows comparative acceleration data from a road test of 4.2 GVW ton truck when fitted with its original 3 litre, six cylinder gasolene engine, and a 2.19 litre, four cylinder diesel engine. Both trucks had the standard gasolene transmission. The similarity between the two curves was very encouraging at the time, especially when the fuel consumption of 15 mpg for the gasolene engine and 25 mpg for the diesel was also considered. The rated speed of 3000 RPM was the same for both types of engine, and it was said that the diesel engine had run smoothly at 4000 RPM. It should be added that the engine was run ungoverned. The savings due to the substantially better fuel economy of the diesel engine were even more enhanced when one considers that gasolene in Great Britain in 1933 cost the equivalent of 17 cents per gallon, whereas the diesel fuel cost only 5 cents per gallon. The main reason for the difference was because the gasolene fuel tax was some eight times higher than that on the diesel fuel. In France diesel oil cost about half of the gasolene price, and in Germany an even greater differential of approx. 70% was seen.

Fig. 4 shows a comparative set of running costs that were issued in 1933 by the Commercial Motor. The considerably lower fuel costs are an obvious point, but the lower maintenance costs, even though the diesel engine was a new type of power unit, shows that one of the other virtues of the diesel engine, was born in those early development days. The diesel engined vehicle had a 20% lower maintenance cost than the gasolene engine.



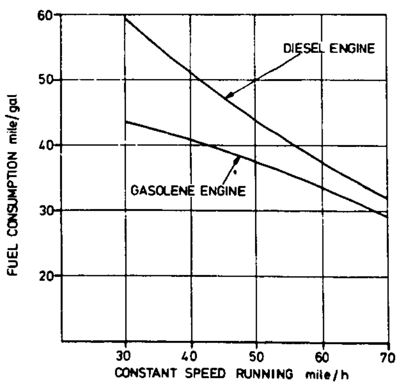
4·2 G.V.W. VEHICLE ACCELERATION WHEN FITTED WITH A GASOLENE AND DIESEL ENGINE

Fig. 3



CONSTANT SPEED FUEL CONSUMPTIONS OF SAME CAPACITY ENGINES IN DIESEL AND GASOLENE FORM

Fig.6



CONSTANT ROAD SPEED FUEL CONSUMPTION

Fig. 7

FIG. 4. RUNNING COSTS (PENCE PER MILE) IN 1933 IN GREAT BRITAIN.

	Petrol Engined Vehicles			
	2 Ton	3 Ton	4 Ton	5 Ton
Fuel	1.33	1.80	2.10	2.63
Lubricants	0.06	0.07	0.09	0.09
Tyres	0.28	0.35	0.44	0.49
Maintenance	1.23	1.42	1.57	1.70
Depreciation	0.54	0.66	0.93	1.05
Total :	3.44	4.33	5.13	5.96

	Diesel Engined Vehicles		
	3 Ton	4 Ton	5 Ton
Fuel	0.38	0.44	0.55
Lubricants	0.12	0.16	0.16
Tyres	0.56	0.74	0.84
Maintenance	1.15	1.26	1.35
Depreciation	0.80	1.10	1.27
Total :	3.01	3.70	4.17

FIG. 5. CHANGES IN THE VEHICLE ROAD TAX IN GREAT BRITAIN IN 1934

Weight Unladen	Gasolene Pneumatic Tyres		Diesel Pneumatic Tyres		Diesel Solid Tyres •
	1933	From 1.1.34	1933	From 1.1.34	From 1 Jan '34
Under 12 cwt.	£10	£10	£10	£35	£46
12 cwt - 1 ton	£15	£15	£15	£35	£46
1 - 1½ ton	£20	£20	£20	£35	£46
1½ - 2 ton	£25	£25	£25	£35	£46
2 - 2½ ton	£28	£30	£28	£35	£46

• For gasolene engined vehicles with solid tyres the road tax remained unchanged at the same rate as the present pneumatic tyre tax.

This Utopia for the diesel engine vehicle could not last, and in Great Britain in 1934, they were penalised against the equivalent gasolene engine by a higher road tax. See Fig. 5. The new tax could be offset to some extent by the conversion from solid tyres to pneumatic tyres, and thus a saving of £11 per annum was possible. So this showed that technology was not altogether being retarded by the new laws.

One novel fact that was put forward was that the increased motor taxes could lead to more deaths. The reasoning behind this statement being that more people would now go back to horse driven carts, and these beasts attracted flies which killed more people by infection than did the motor vehicle by road accidents at that time.

Further pressure was applied to the diesel engine in 1935 when the British Government realised that there was a danger to its gasolene revenue, and so they increased the tax on the diesel fuel and made it equal to that on the gasolene.

A number of statements made at the time make interesting reading such as the Minister's statement that "The oil engine can do as much work on 1 gallon of fuel as the petrol can do on $1\frac{3}{4}$ gallons", and the pro-diesel faction who "believe that the oiler will continue to live and flourish but it must not be stunted in its youth", and the increase of tax even pleased some people as it would "encourage the steam vehicle trade". Times don't change that much do they?

This increase of tax was a considerable blow to all concerned in the diesel market, but work continued as the better fuel economy of the diesel was still worthwhile, but it now became even more essential that the first cost should be maintained as low as possible. This meant that the production principles and techniques that applied to the gasolene engine manufacturing industry, had also to be applied to the diesel engine wherever possible. This was especially essential for the smaller diesel engine, as it took that much longer to offset the first costs with the lower fuel consumption, simply because the total quantity of fuel consumed was small. The manufacturer who made both gasolene and diesel engines had an advantage in that he had many components at hand which he could design into both engines and maximise on rationalisation between the two types of engines.

The fuel injection equipment was, and still is, an expensive component in rèlation to the total engine first costs of a small diesel engine. This was, therefore, one of the main factors why the engine first costs were so high, and this coupled with customer inexperience of this type of equipment was a holding factor in the possibly even more rapid development of the smaller engine. Due to the commendable reliability of these first fuel pumps it was not long before most operators' doubts were dispelled and it soon became obvious that the reliability of the fuel pump was considerably better than that of the electric ignition equipment fitted to the gasolene engine. Consequently, the lower maintenance and down time costs were soon seen as a further bonus to the diesel engine vehicle operator.

The first diesel powered saloon cars.

It was obvious that the excellent fuel economy of the diesel engine would also prove attractive to the private motorists, and so the early 1930's saw parallel tests being run in both trucks and passenger cars.

The need for comparative size, weight, power and engine speed between the diesel engine and the gasolene engine became even more important when installation into a passenger car was considered. Further factors had also now to be considered such as noise, vibration and smell.

The first production diesel engined car was the Mercedes Benz "260D" which was powered by a four cylinder 2.6 litre engine which gave 45 HP at 3000 RPM. The car was normally fitted with a 2.3 litre gasolene engine. This diesel engine, the OM138, was a descendant of the pre-chamber truck engine and proved to be the very successful forerunner of a whole range of Mercedes diesel engines designed to suit the passenger car. The fuel consumption of 30 mpg and a maximum speed of 60 mph was very commendable, especially when the size and weight of the vehicle, which was really only a small transition from the light commercial vehicle, was considered. This car gave excellent service to many people, but of course the war years prevented any further development on these lines, and it was not until 1949 that a new model, the 170D, was seen.

The passenger car application was also being looked at in England in the early 1930's with an eye to Diesel conversion. In 1933, a 2.9 litre Perkins engine was installed in a gasolene production car and a creditable running cost of $\frac{1}{8}$ cent per mile was seen with equivalent performance to that given by the displaced gasolene engine.

Various capacity diesel engines were tested and one of the bigger conversions was a 3.8 litre Gardner engine rated at 83 BHP at 3200 RPM which replaced a 3.5 litre gasolene engine. This saloon car had a top speed of 83 mph and an overall fuel consumption of 44 mpg, which was considerably better than the 16 - 18 mpg achieved with the gasolene engine. A point of note was also that the conversion only added 100 lbs. to total vehicle weight.

The excellent fuel economy and reliability of these cars attracted people who had to cover very long distances, but even greater benefits were to be seen by the operators of stop start vehicles such as small delivery vans and taxis.

Further impetus to the development of the diesel engine was given by the political climate in Europe during the mid and late 1930's. Independence from imported fuels was aimed at, and so a variety of home produced fuels from coal and gas fuel were tested. As it was simpler to convert a diesel engine to operate on a variety of fuels rather than a petrol engine, it was generally the former which was the basic engine used for the development work.

The Second Era.

In 1949, Daimler-Benz produced the 170 Series of saloon cars. This model was the forerunner of a whole new series of passenger cars produced by this company, and has seen gasolene and diesel engines installed in parallel up to the present time.

The 1.76 litre diesel engine (OM 636) embodied much of the experience gained from the earlier 2.6 litre engine, and this enabled the smaller engine to have a rated speed of 3200 rpm and an output of 21.6 bhp/litre. The popularity of this vehicle is shown by the fact that 27,000 170D's were sold in the three years from 1949 to 1952. The first cost of the diesel engined car was only $185 more than the equivalent petrol model, and with a fuel consumption of 40 - 45 mpg, it took very little time before the diesel car was making a considerable saving.

This engine was developed further and in 1953 the 180D was introduced with the four cylinder engine now rated at 43 bhp at 3500 rpm, 24.4 bhp/litre, and a capability of 3800 rpm. These engines had a stroke/bore ratio of 1.33, but when a new 2 litre engine was introduced in 1959, it had a reduced ratio of 0.96, which allowed a higher operating speed of 4350 rpm and a specific output of 27.5 bhp/litre.

The European Continental countries still gave an extra boost to the development of the diesel engine in the early fifties by keeping the cost of diesel fuel well below the gasolene costs, whilst in Great Britain the difference in 1954 was only a little over 2.5 cents. There was also very little difference in fuel costs in the U.S.A. at this time and, so again, the incentive was low.

Various European Continental manufacturers now began producing diesel powered cars, such as Fiat in Italy and Borgward Hansa in Germany and eventually in 1954 the Standard Motor Company Limited began producing a saloon model in England. The essential point on first costs was pointedly shown by an automotive magazine at the time which stated that 61,200 miles was needed to be covered by this car before the high price differential of $640 was offset. This mileage was required on the basis of the diesel engined car giving 40 mpg as against 23 mpg of its equivalent gasolene engine.

The top speeds of the diesel car were generally some 10 - 20 mph lower than the gasolene, but even more frustrating was the poor acceleration. This generally was due to the prime essential of interchangeability. The specific output HP/litre of the diesel engine has always been lower than the gasolene and, as the engine bulk dimensions had to remain essentially the same for both engines, this meant that the diesel had a 10 - 15% lower power output, and a maximum engine speed between 1000 - 1500 rpm lower than the gasolene. In many cases the transmission ratios were not changed and so the vehicle performance suffered again from this. Sometimes an overdrive ratio was fitted which enabled a higher top speed, but the poor acceleration was generally seen as a big disadvantage to the average motorist.

The driver who covered very long distances and required a reasonable cruising speed with good reliability, found the diesel car to his liking.

An even more beneficial application was in the vehicle that used a stop start and low load factor type of operation.

The diesel engine has nominally a constant volumetric efficiency and compression ratio through the load range at a given speed, whereas the gasolene engine has to contend with falling values at part load due to the throttling of the air flow at these conditions. This difference is shown in the better part load economy of the diesel engine and so the stop start or part load applications show the diesel engine to considerable advantage.

Fig. 6 shows how the specific fuel consumption curves of the same capacity engine when tested in diesel and gasolene forms diverge at the part load condition. This feature when transferred to actual road running results shows that the light load running gives approximately three times the fuel saving seen at the high load factor running. See Fig. 7.

Various types of vehicles saw the economy of the diesel engine in this way in the mid 1950's, and the engine was used in applications varying from taxis to delivery vans and road sweepers.

The rapid increase in the use of the diesel engine for taxi applications was most spectacular in Great Britain. Fig. 8 shows how the first taxi was

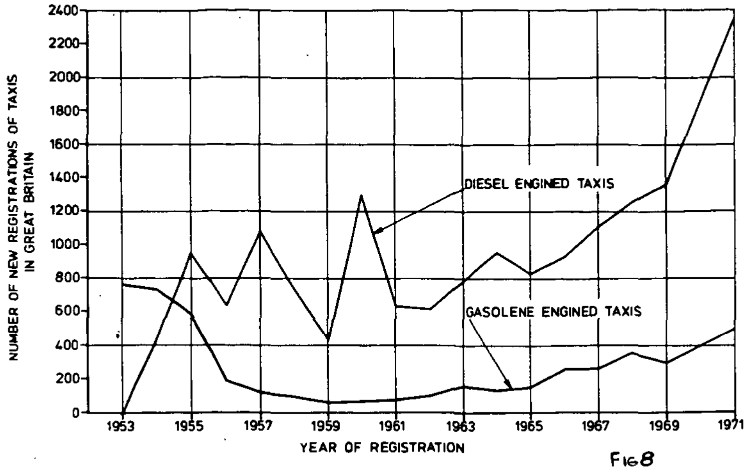


FIG 8

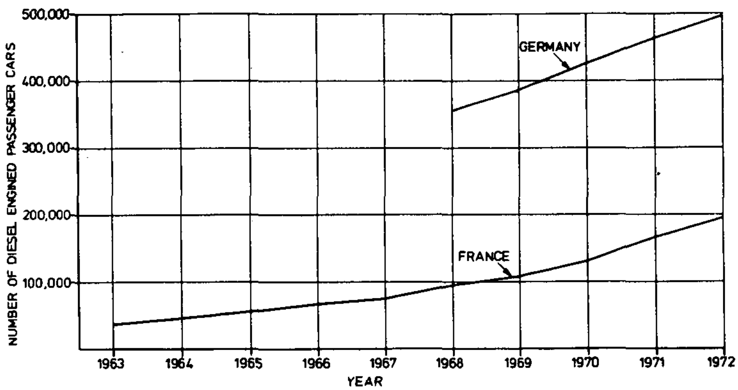


FIG 9

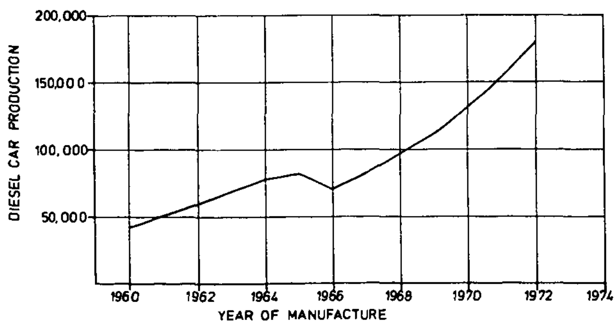


FIG 10

registered in 1953 and within 2 years the number of new registrations had overtaken that of the gasolene engined taxis. The late 1950's saw an erratic trend, possibly due to the economic climate at that time, but since 1961 the increase has shown a positive upwards swing. The rising trend of the gasolene taxi since 1961 is due to the number of smaller companies and individuals who are using their private cars in this market.

Fig. 9 shows how the German diesel passenger car market has always been the largest in the world, with an impressive figure of 0.5 million diesel cars being used in 1972. It is estimated that 45,000 taxis will be registered in Germany during 1972/73, and 80% of these will be diesel powered. This shows that the vast majority of diesel engined cars are being run by companies and the public for their private use and overall fuel consumption and reliability must be priority features as they are in this market in any country. The position in France since 1963 is also shown on Fig. 9, and although the actual numbers involved are much smaller, the trend shown from 1969 - 1972 is parallel to the German experience.

The owner of a motor car who travels above the average annual mileage, say 25,000 miles or more, will see the benefit of running a diesel car, and the auto-routes seen across the European Continent are ideal roads for this type of driving, as are the American freeways.

In Great Britain we do not have the road system, or even possibly the square mileage of country, to see the same usage of diesel engined cars as on the European Continent, and consequently the majority of these vehicles are used as taxis. As the fuel savings are so much greater at these part load running conditions, the mileage necessary to offset the higher first costs is much less. A typical difference in the fuel consumption for a London taxi cab type of duty would be 20 mpg for the gasolene engined taxi and 35 mpg for its diesel engined equivalent.

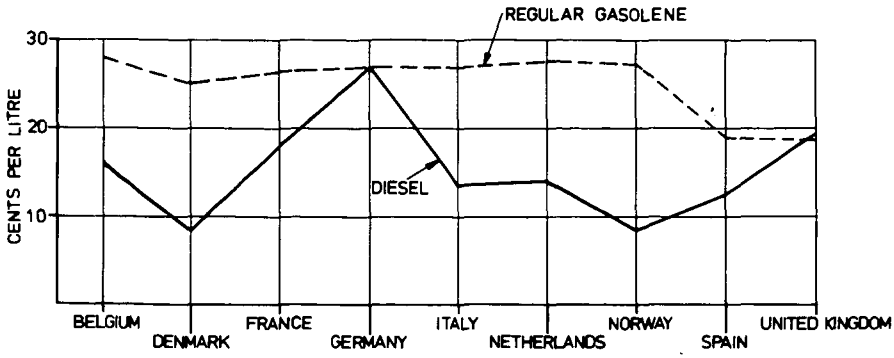
The 12cwt - 1 ton light van market is a very high quantity market, but as yet the diesel engine has made very few inroads. This again is essentially because of first costs, although to some extent the performance penalty is still felt in this low weight vehicle.

The 1 - 1½ ton vehicle market is also a very lucrative market, and the diesel engined vehicle is showing a steady rise here.

The light truck applications used by local Authorities for road cleaning, refuse disposal and other city work, see the advantages of the diesel in these applications. The part load economy again shows its benefit in these trucks, and the higher first costs can be offset in about 3 years. The reliability of these engines giving less 'down-time' and 'call out' problems is a further added bonus. These trucks give about 10 years' service before a major overhaul is necessary.

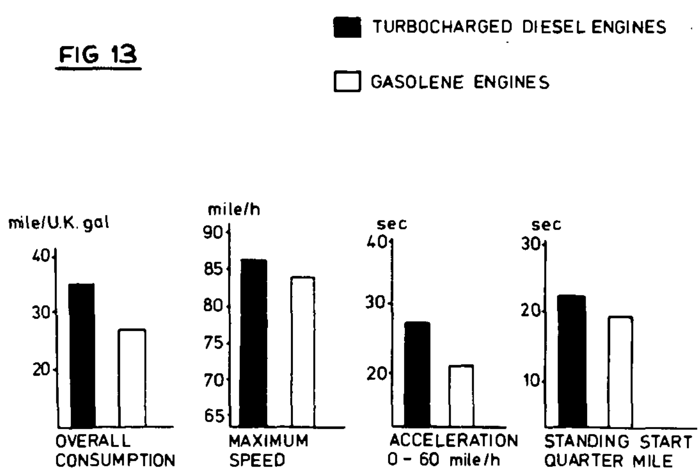
If we look at the production rate of the diesel engined car in Europe over the last 15 years, we see that there has been a positive increasing rate - See Fig. 10. The graph does not include conversions but only production line cars.

This trend proved attractive to more gasolene engine car manufacturers and today we have three major manufacturers who produced a total of 180,000 diesel engined saloon cars in 1972. Between them, these manufacturers - Mercedes Benz, Peugeot and Opel, produce a wide range of diesel engined vehicles ranging from a small saloon to an 8 seater limousine.



RETAIL PRICE OF DIESEL AND GASOLENE FIG.11

FIG 13



All the vehicles have four cylinder engines, even the biggest which has a 2.4 litre engine, and the highest rated speed is now a creditable 5350 rpm seen from the Peugeot cm^3 engine.

Whilst the diesel engine has been making considerable strides in its development with an eye on the saloon car market, the gasolene engine has, of course, equally been intent on further development and, consequently, it would be true to say that the performance gap has not decreased. The performance of the gasolene engined car has improved substantially since the end of the 2nd World War, and so in a direct comparison the gasolene car is still superior in acceleration and maximum speeds. But we must not let this overshadow the developments that have been seen in the diesel engine, where a 50% increase in rated speed has been achieved and specific outputs have nearly doubled. Without a doubt, the saloon car market has provided the stimulus for this development, and many people believe that the potential world market for the diesel engined car and light truck has yet to be exploited.

Today's gasolene engined car has on average still a 10 seconds advantage on a 0 - 60 mph acceleration test, and a top speed some 15 - 20 mph faster, but in these days of increasing legislation to reduce speed limits, the diesel car performance giving 75 - 85 mph is more than adequate.

We still have the old problem of first costs and the basic price differential varies from $250 to $750, but equally so we also still have the considerably better fuel consumption from the diesel car. Such adjectives as "astonishing", "tremendous" and "dramatic" are frequently used when people compare the fuel consumptions of these cars and, in general, they give 60 - 70% miles more per gallon than their gasolene engined counterparts.

We have seen how economy has always been a paramount factor in the sales of diesel cars, and this was undoubtedly helped by the beneficial differential in fuel costs seen in most European countries. It is possibly a demonstration of the insight and gratitude of the politician to see from Fig. 11 that Germany, who for so long has been the leader in the diesel car market, has now, along with the United Kingdom, the dubious honour of having no or even an adverse cost differential when compared with current gasolene prices. Extra strength is really given to the case for the diesel engine by this fact, as the fuel economy is still being seen as a worthwhile factor in purely mpg terms.

THE FUTURE:

If we now look into the future, how do we see the diesel engined saloon car in the light of legislative and fuel resource pressures.

The use of the I.D.I. combustion principle for the small diesel engine began, as I said before, at the very beginning of the development era of the diesel engine. Some people might call it foresight, fortuitous or just luck, that this type of engine is now proving to be a much better emission controlled engine than either the D.I. diesel engine or the gasolene engine. But really the fact that they were chosen because they had lower cylinder pressures, along with better breathing, is the reason why this combustion principle is now showing to advantage in these days of low NO and noise. Lowering the rates of pressure rise and peak cycle temperatures by retarding the injection is a well known principle and in the I.D.I. engine this also has the added benefit of reducing the exhaust smoke. This later timing also reduces the combustion noise levels and so we gradually have a situation where the previous disadvantages of the diesel engine are also being reduced. Taking the old problem of installation. If we can sufficiently decrease the rate of cylinder pressure rise and hence the combustion noise, at both high and low speeds, it may be possible to reduce the bulk and weight of the diesel engine and so reduce the installation problems, and at the same time reduce the first cost differential.

This principle has of course to be investigated in considerable detail and analysis, or the situation will arise where the reduction in engine bulk will allow more noise to be released.

By extensive analysis of the cylinder block loading and vibration it may be possible to design a block which can distribute the loading more effectively and so reduce the noise generating sources along with a reduction in engine bulk.

The diesel knock becomes more obtrusive in the car application at the lower engine speeds, and means of reducing ignition delay periods and smoothing out the rates of cylinder pressure rise seen at part load conditions will have to be found before the average motorist will be satisfied. His previous experience of such sounds with his gasolene engined car has usually given him visions of failing bearings and pistons, and possible some re-education is needed to convince him that the diesel engine is designed to withstand these loads.

The U.S. legislation on g aseous emissions has caused enormous headaches for all engine manufacturers all over the world.

The manufacturers of the gasolene engine have been the hardest hit, but after all it was them who created the problem in the first place and are now experiencing the greatest difficulty in meeting the stringent requirements.

Many estimates and gloomy predictions have been made on the reduced power, increased fuel consumption, and increased first costs of the gasolene engined car that can meet the 1975/1976 and subsequent years' legislation. The Honda CVCC, and various rotary engine design concepts have been developed so as to meet the legislation, whilst the standard reciprocating gasolene engine has had to introduce many external innovations. The I.D.I. diesel engine has many of the required design and combustion features already built into it and any further modifications will generally come about by engine internal modifications. This means that the offending pollutants are not generated in the first place, and so the need for expensive corrective action is not required.

The number of engine modifications required by the diesel engine are relatively small if the 1975/76 Federal limits are to be met, and it is generally true to say that the stricter the limits the more able the diesel engine is to meet them. A very small power and SFC penalty is expected from the diesel engine if it has to meet the projected 1975 California legislation, and with only marginal increased cost. Very few figures are released by the gasolene engine manufacturer on the effects of tidying up his emissions problem, but considerable power derates, increases of vehicle weight, increases of first costs, and most critical of all increased fuel consumption, are all factors which will generally apply.

The lower specific output of the diesel engine has to be increased if it is to effectively compete on a performance basis with the gasolene engined saloon. This increase can come about by turbocharging and along with it, further improvements in fuel economy. The turbocharger will obviously increase the first costs, but these will be more than offset by the very

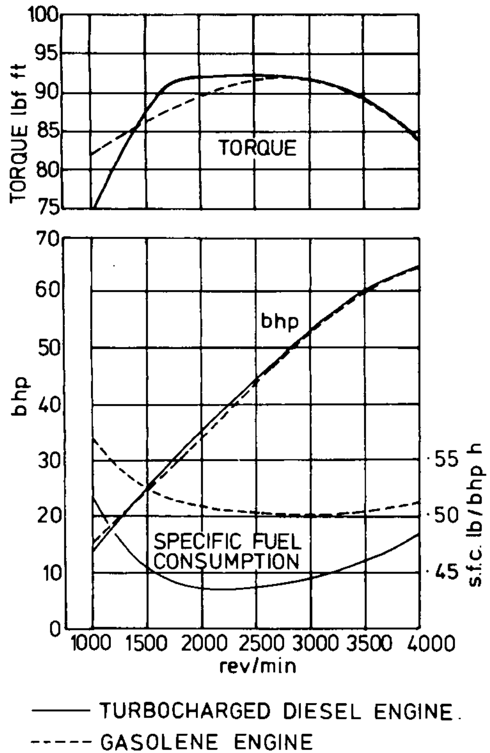
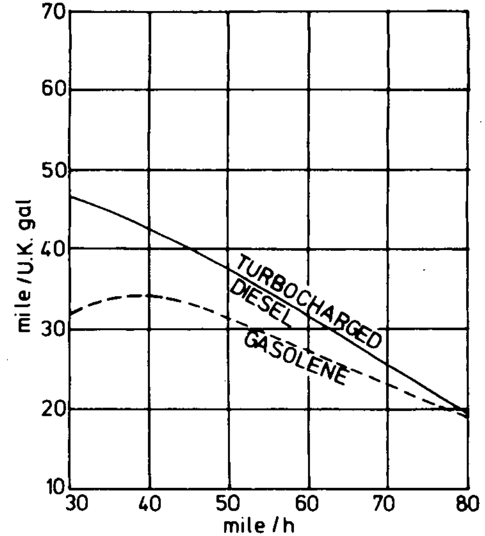


FIG. 12



CONSTANT SPEED FUEL CONSUMPTION

FIG.14

expensive catalytic converters required by the gasolene engine.

Fig. 12 shows a test bed comparison between a 4-cylinder 108 cu. in. turbocharged diesel engine and a 104 cu. in. gasolene engine. The gasolene engine was in standard, non-de-toxed condition. Since 4000 rev/min was the maximum speed of the diesel, the gasolene curve was also discontinued at this speed although not reaching a maximum until 4800 rev/min. The superior fuel consumption of the diesel is clearly shown.

Each engine was installed in a UK Ford passenger car and comparative road test data obtained. Histograms of fuel consumption, maximum speed and acceleration are shown in Fig. 13. The standing start acceleration of the diesel powered vehicle was slightly inferior to the gasolene car, due mainly to the higher rotating inertia of the diesel engine and heavier installed weight. Top gear acceleration above 40 mph was, however, better with the diesel engine, as was the top speed. Fuel consumption was considerably better with the diesel, particular at lower speeds. Fig. 14 shows the steady speed fuel consumption at various speeds.

So the turbocharger will give improved performance and fuel economy to the diesel engined vehicle, whilst its gasolene counterpart is subjected to reduced performance and economy.

Two more fundamental yet substantial changes may be required to the diesel saloon philosophy, which affect both engine and car manufacturer, if this type of vehicle is to be fully accepted.

First, engines of six cylinder configuration may be required, one manufacturer has split the difference and is working on a five cylinder engine, but if powers over 120 BHP are required then a turbocharged six cylinder will be the answer.

Second, the transmission should be designed for the diesel engine and, if the engine is turbocharged, then a torque converter should be matched to its torque curve.

I therefore foresee the role of the small high speed diesel engine increasing in the light duty market, and this market potential should provide a real stimulus to the diesel engine manufacturer to further improve his product and prove that the image of the diesel engined car is due for a well deserved brush-up.

The vehicle manufacturer has to accept that the transmission has to be developed around the diesel engine, and if a concerted effort was made by all parties concerned, the late 1970s and into the 1980s could see improvements in both environmental conditions and a substantial reduction in the rate of exhaustion of our valuable fuel resources.

CURRENT LIMITS FOR LIGHT DUTY DIESEL ENGINES:

1. Power - This is dependent of speed (rev/min) and brake mean effective pressure (b.m.e.p.).

2. Speed - For the size of engine considered, the limiting factor is usually mean piston speed. Problems arise if diesel engines are operated for sustained periods at piston speeds over 2500 ft/min. Some gasolene engines operate at up to 3500 ft/min. Fig. 15 shows the permissible stroke dimension for various maximum engine speeds.

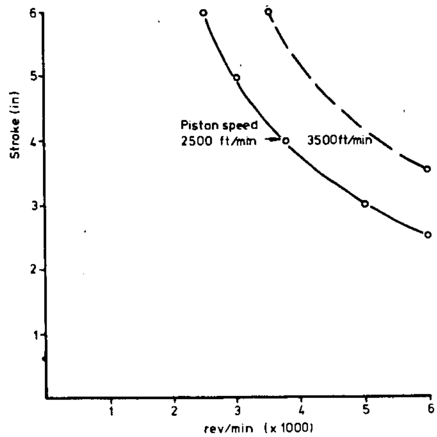


FIG.15

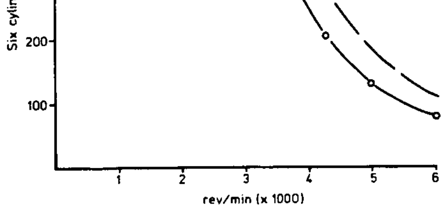


FIG. 16

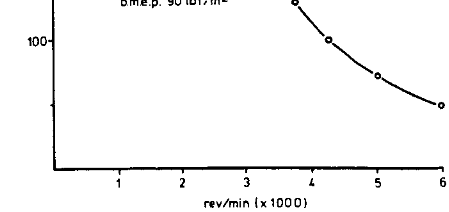


FIG 17

3. Stroke to Bore Ratio - For indirect injection diesels, a stroke/bore ratio of between 1.0 and 0.85 is possible. This therefore sets a limit on cylinder capacity for a given rev/min. and piston speed. Fig. 16 shows the permissible maximum speed of various capacity six cylinder engines.

4. B.M.E.P. - Normally aspirated diesel engines should produce 90 lbf/in^2 b.m.e.p. at maximum speed. Using this value, Fig. 17 shows the horsepower limit at various rated speeds for the six cylinder engine.

5. Supercharging - More power can be obtained by turbocharging, but limited by the temperature of pistons, rings, cylinder head face and valves, and cylinder pressure. By turbocharging, an increase in power of 30% may be expected.

6. Engine bulk - Diesel engines tend to be longer than gasolene engines due to water passages between bores, more robust crankshaft and bearings and heavy duty timing drive.

   Siamesed cylinders may be used for light duty applications, but problems due to cylinder distortion are likely.

   The height is usually greater than for an equivalent gasolene engine, due to longer stroke and thicker head. Carburettors, however, frequently add to the height of gasolene engines. Oil pans tend to be deep to hold a larger volume of oil.

   There is little difference in engine width, particularly in-line engines.

   The bulk of a diesel is likely to be up to 50% greater for a given cylinder capacity.

7. Engine weight - Where cast iron is used for the blocks and heads of both diesel and gasolene engines, the diesels are usually heavier. This can amount to 100% more for equal power, normally aspirated.

   Fig. 18 shows a comparison between a light commercial vehicle diesel engine and a typical compact car gasolene engine.

FIG. 18.

ENGINE COMPARISON

MAIN DIMENSIONS.

	Diesel Engine	Six Cylinder Gasolene Chrysler 225 ins^3 "RG" Inclined 30° from Vert.
	inches	inches
Cylinder block length	27.6	26.1
Length engine from rear face cylinder block to front of fan	36.6	31.0
Height of water pump	8.2	6.7
Depth of sump	10.6	8.6
Height above crankshaft	18.4	18.3
Overall height	29.0	26.9
Width L.H. Looking from drivers seat	10.7	9.0
Width R.H. Looking from drivers seat	12.5	13.8
Overall width	23.2	22.7
Engine weight (lbs.) (dry)	708	475
	Flywheel plus backplate. Starter plus alternator plus fan.	Alternator plus air cleaner only. 555 lbs. if to equivalent specification